



# Update on sPHENIX Calorimeter Beam Test

Craig Woody

EIC Calorimeter R&D Meeting

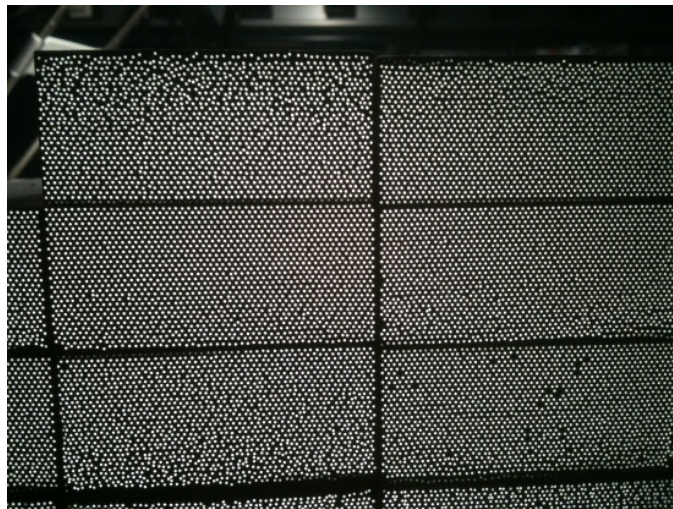
November 10, 2016

# Overview of the Beam Test

- April 6 – May 3, 2016
- Test of sPHENIX EMCAL + HCAL Prototypes
  - ❑ EMCAL
    - 8x8 array of 1D projective modules
  - ❑ HCAL (Inner + Outer)
    - 4x4 towers each
- ~ 40 contributors (including support staff at BNL)  
→ 9 Institutions

# EMCAL Prototype

Half of the absorber blocks were manufactured at THP and half at UIUC

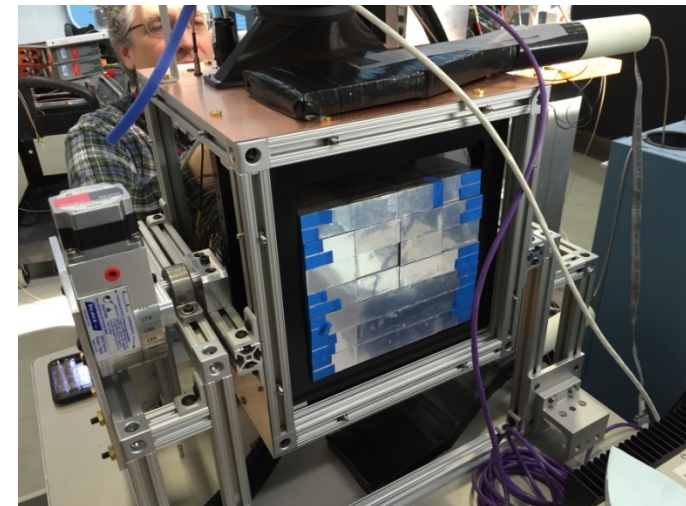


Density varied from  
~ 8.5 – 10 g/cm<sup>3</sup>

Slight fiber  
misalignment at  
one end but can be  
easily corrected in  
the future

8x8 array of towers

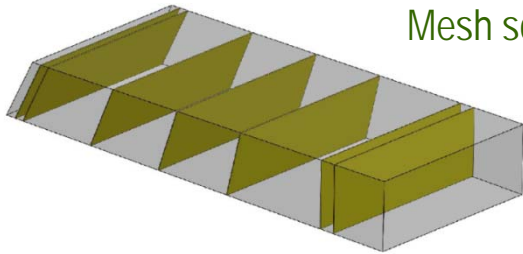
THP 9.3	THP 9.3	THP 9.6	THP 9.6	THP 9.5	THP 9.5	THP 9.4	THP 9.4
THP 9.5	THP 9.5	THP 9.5	THP 9.5	THP 9.6	THP 9.6	THP 9.0	THP 9.0
THP 9.2	THP 9.2	THP 9.6	THP 9.6	THP 9.2	THP 9.2	THP 9.4	THP 9.4
UIUC 9.6	UIUC 9.6	UIUC 9.3	UIUC 9.3	THP 9.4	THP 9.4	THP 9.6	THP 9.6
UIUC 9.5	UIUC 9.5	UIUC 9.5	UIUC 9.5	THP 9.4	THP 9.4	THP 9.3	THP 9.3
UIUC 9.5	UIUC 9.5	UIUC 9.5	UIUC 9.5	UIUC 9.4	UIUC 9.4	UIUC 9.6	UIUC 9.6
UIUC 9.2	UIUC 9.2	UIUC 9.6	UIUC 9.6	UIUC 9.3	UIUC 9.3	UIUC 9.3	UIUC 9.3
UIUC 9.5	UIUC 9.5	UIUC 9.6	UIUC 9.6	UIUC 9.3	UIUC 9.3	UIUC 9.2	UIUC 9.2



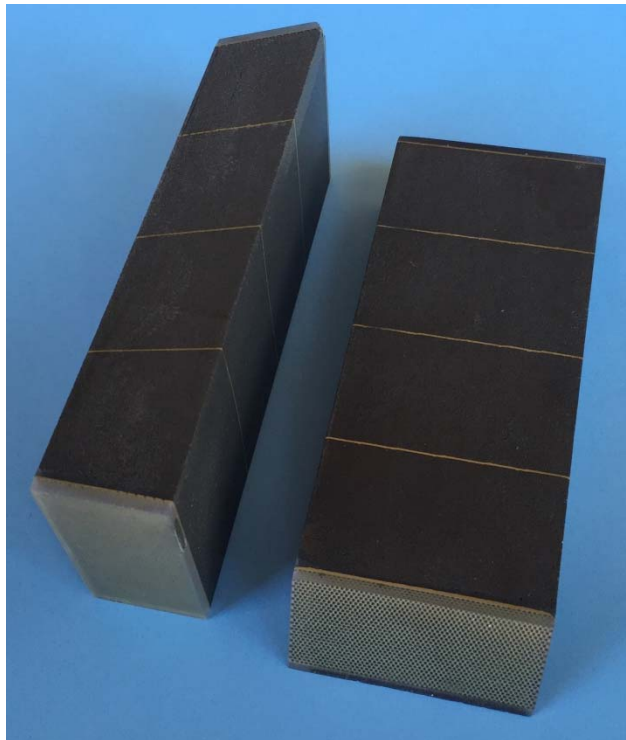
# W/SciFi Modules

## 1D Projective

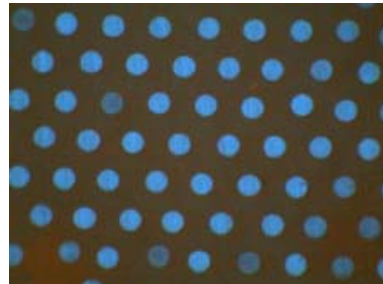
Mesh screens



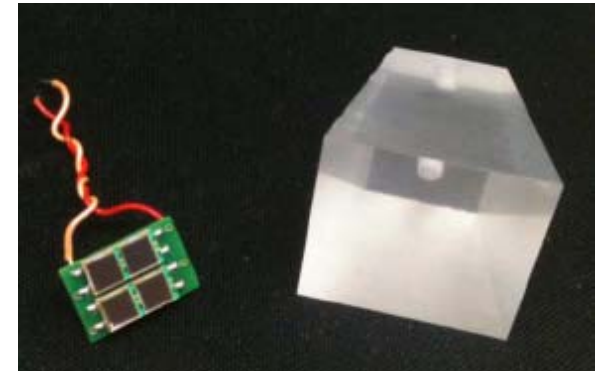
Produced at UCLA, BNL, UIUC and THP



Fiber ends are finished by  
with fly cutting



Light guides and SiPMs are  
attached to module ends to  
form towers





# HCAL prototypes

Inner and Outer HCAL prototypes each consist of 4 x 4 towers

- Inner:  $\sim 0.5 \text{ m}^2$  (56 x 94 cm<sup>2</sup>)
- Outer:  $\sim 1.2 \text{ m}^2$  (74 x 165 cm<sup>2</sup>)



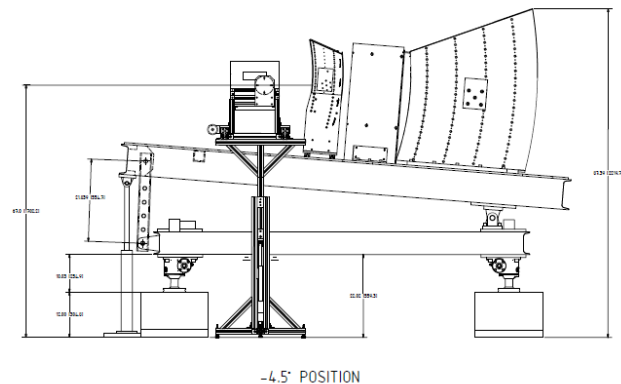
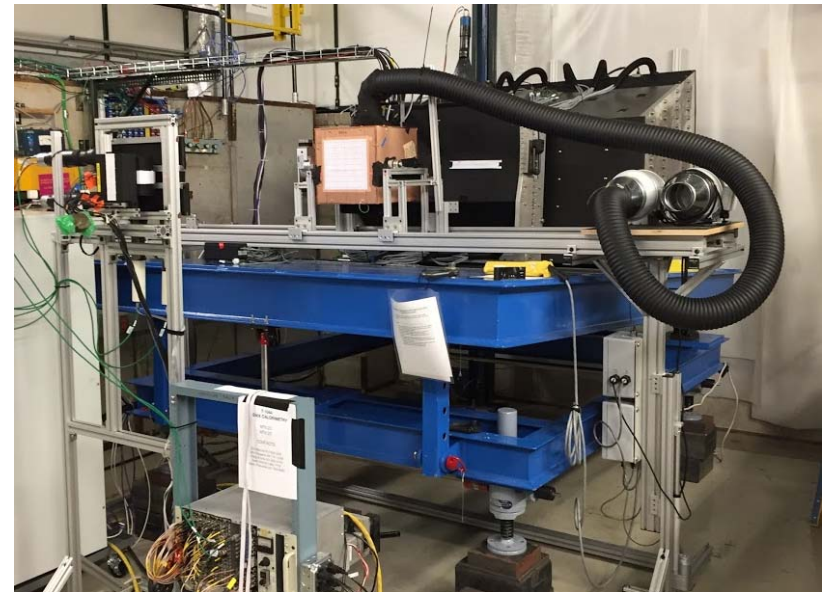
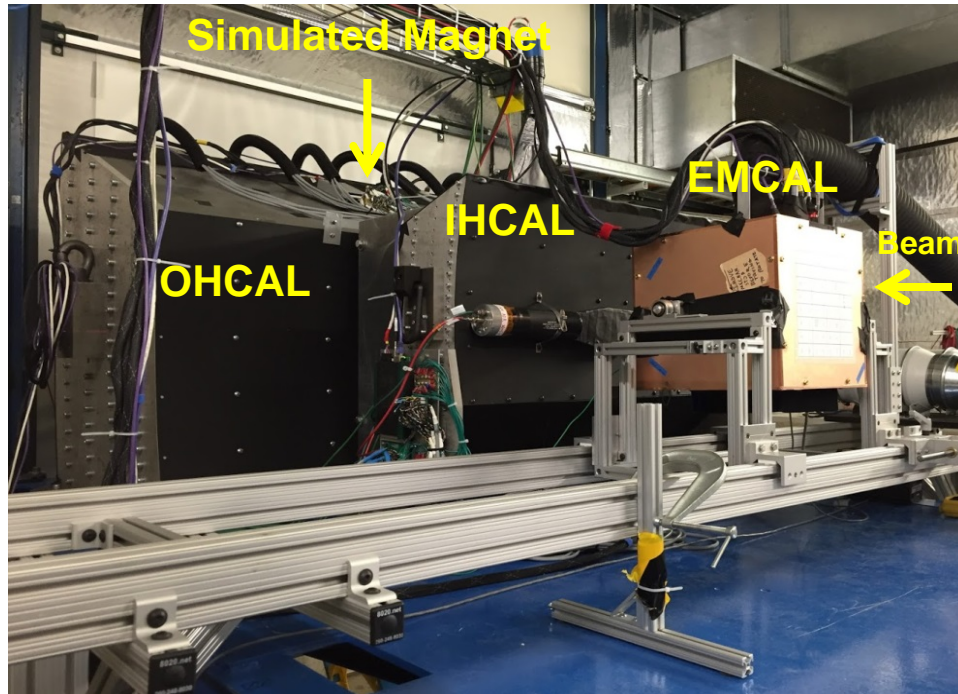
Outer HCAL prototype with assembled steel plates and readout electronics



Polystyrene scintillating tiles (7 mm) with WLS fiber (1 mm) in groove. One SiPM reads out both ends of fiber. SiPMs from 5 tiles summed together to form one tower

# Test Setup at Fermilab

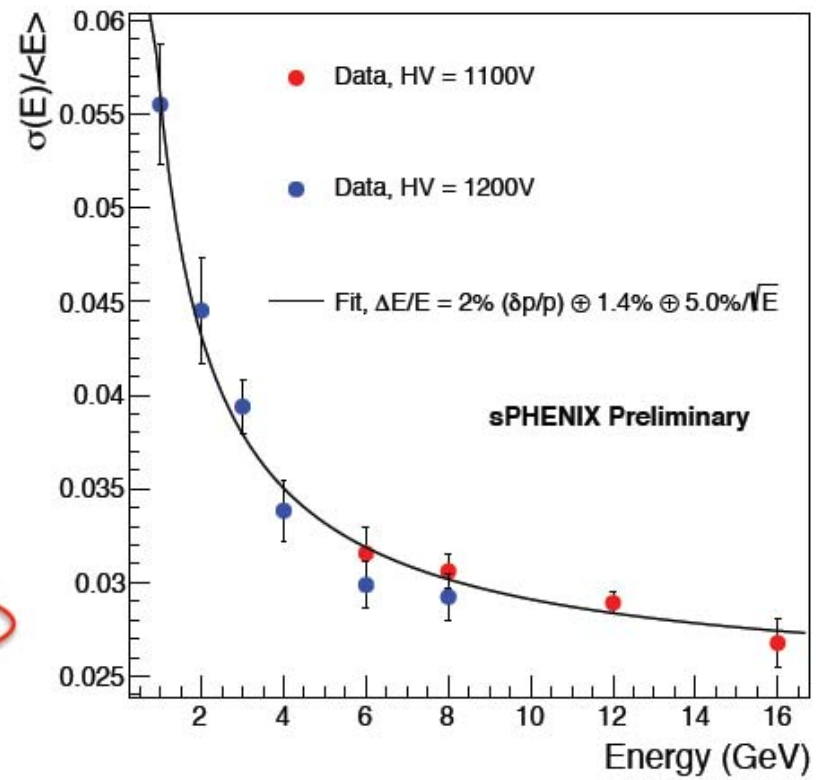
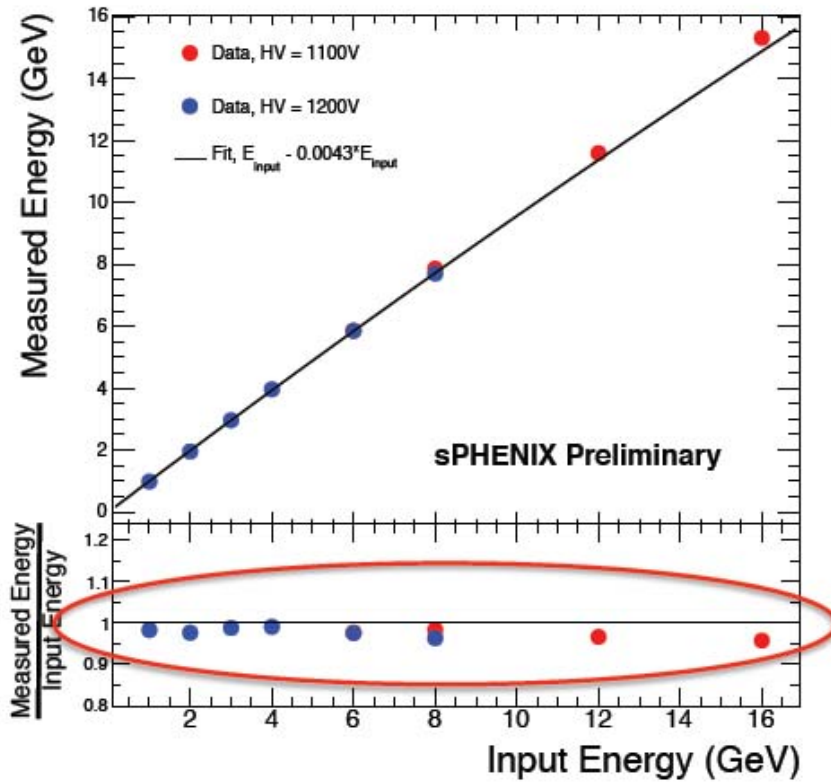
All three prototype calorimeters in the beam line at Fermilab



Three calorimeters in their sPHENIX configuration

Measured at three tilt angle positions ( $0, \pm 4.5^\circ$ )

# Lead Glass

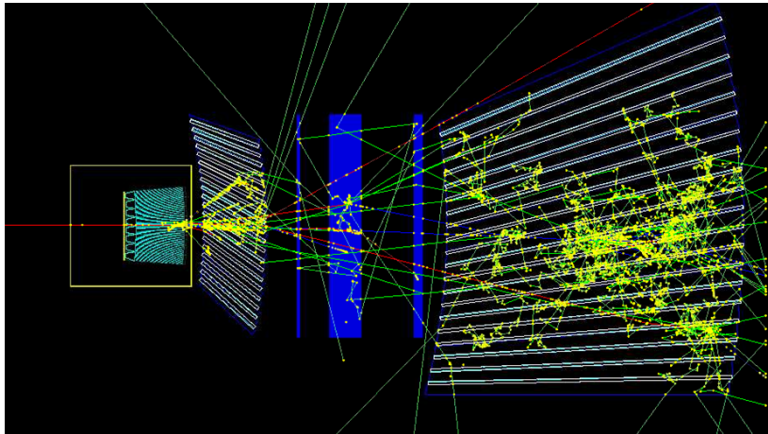


Input Energy	Measured/Input Energy PbGL
1 GeV	0.982731
2 GeV	0.976239
3 GeV	0.98766
4 GeV	0.990394
6 GeV	0.976067
8 GeV	0.973073
12 GeV	0.966285
16 GeV	0.957336

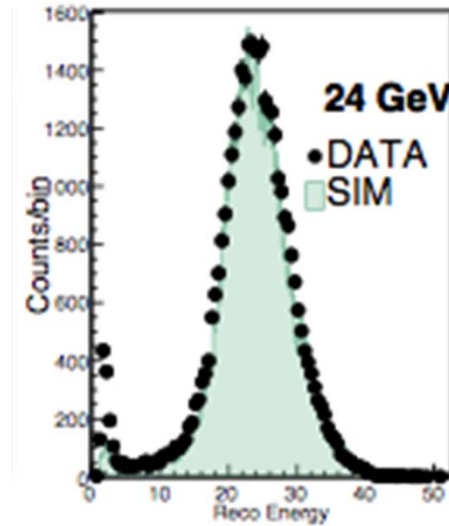


# Simulations

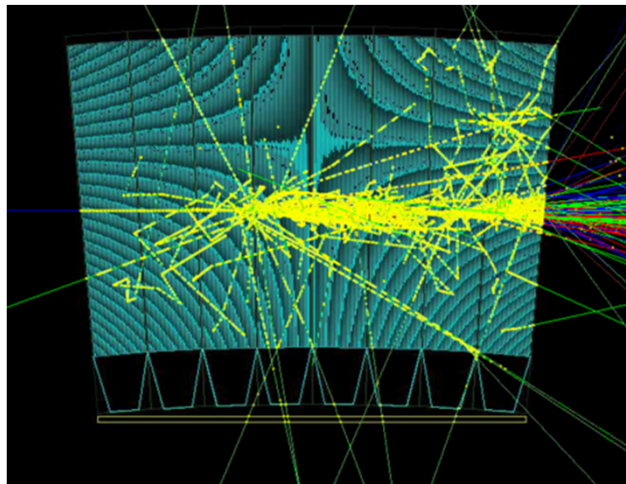
Entire test beam setup was simulated in GEANT4



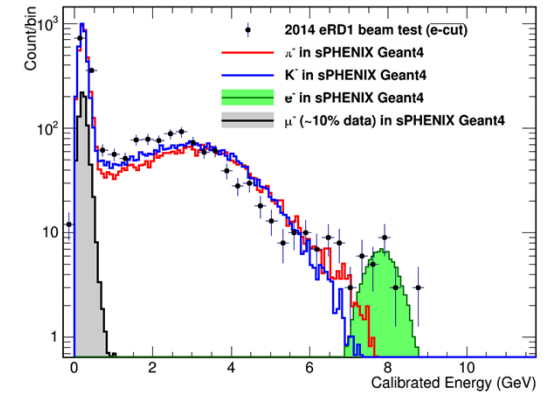
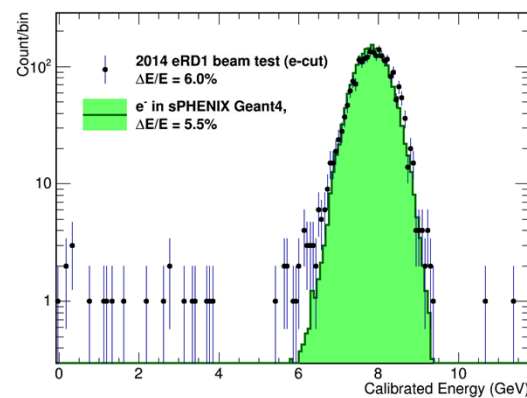
Hadronic shower in 3 calorimeters



Comparison of IHCAL+  
OHCAL line shape with  
simulation



Hadron entering EMCAL in “nose down” position



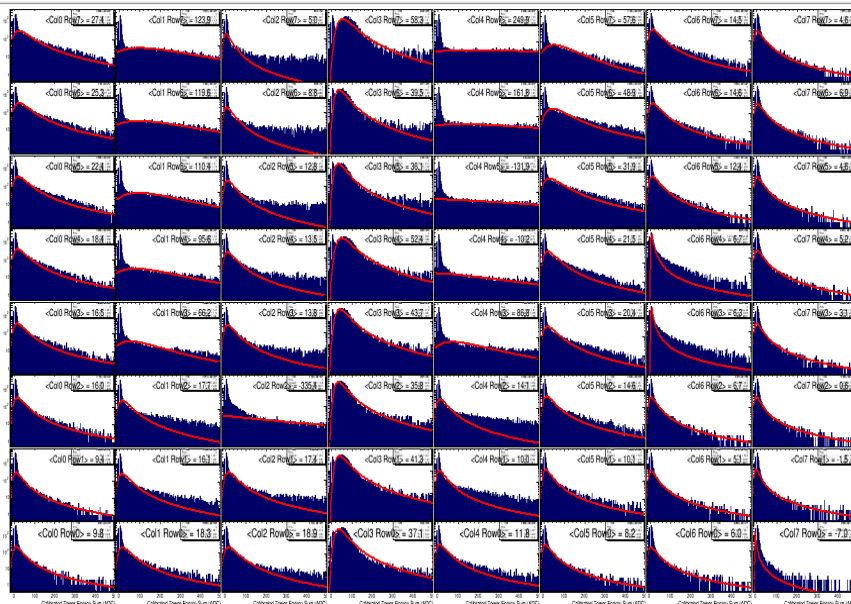
Comparison of EM and hadronic showers in EMCAL prototype  
with eRD1 test beam data



# Calibrations

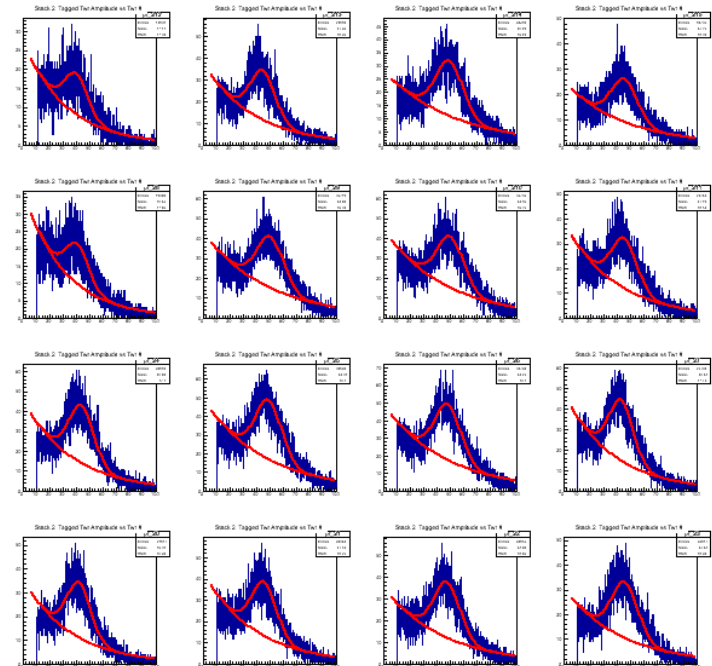
MIP peaks in each detector used to equalize response for each tower and set approximate energy scale

EMCAL calibration done with 120 GeV p's  
 Detector in “nose down” position  
 Beam passes through 8 towers at a time  
 Edep ~ 30 MeV per tower  
 Preamps set to x16 higher gain



Beam ↑

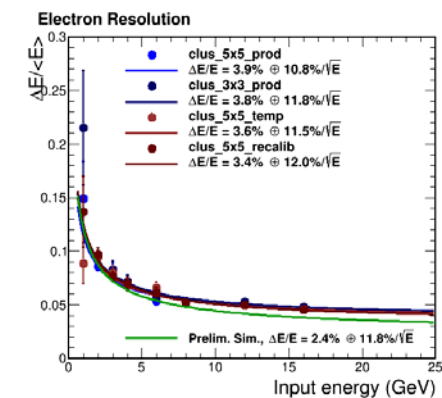
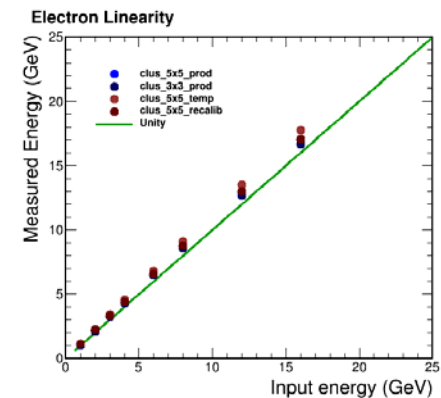
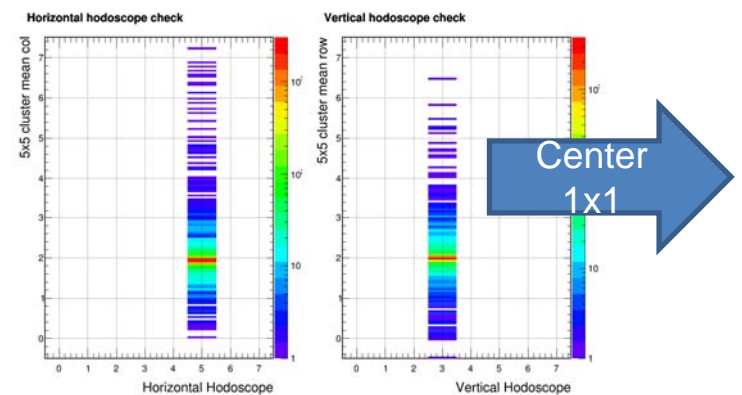
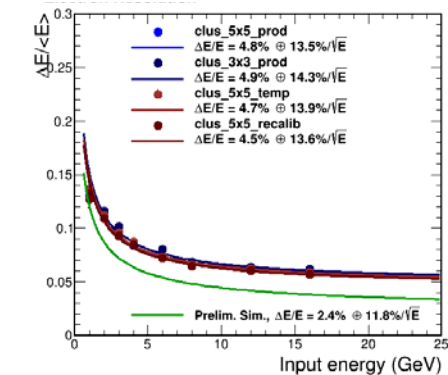
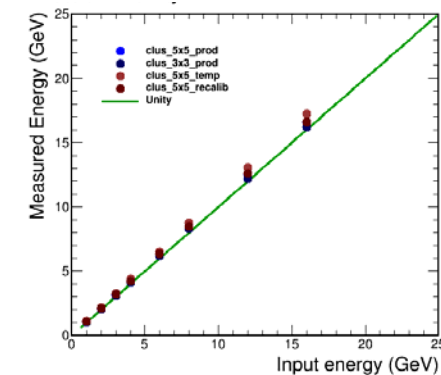
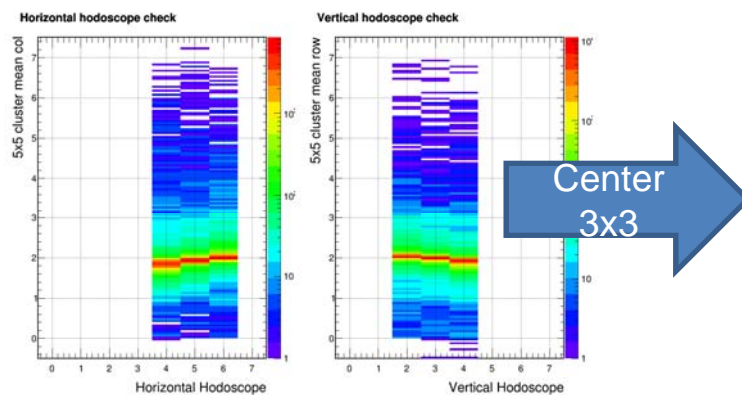
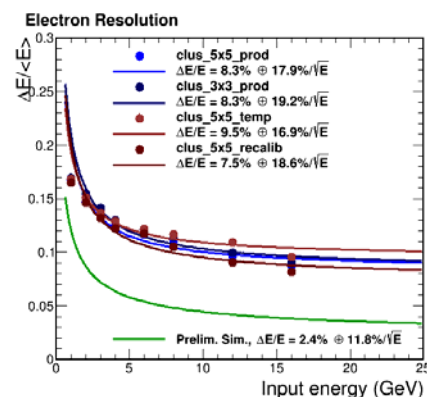
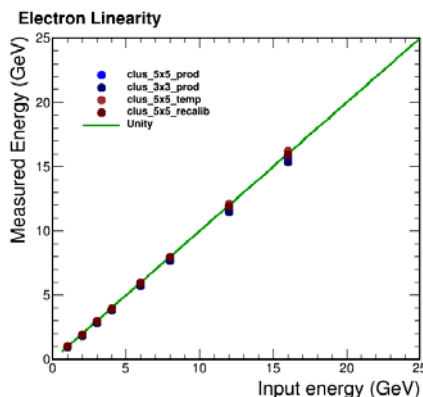
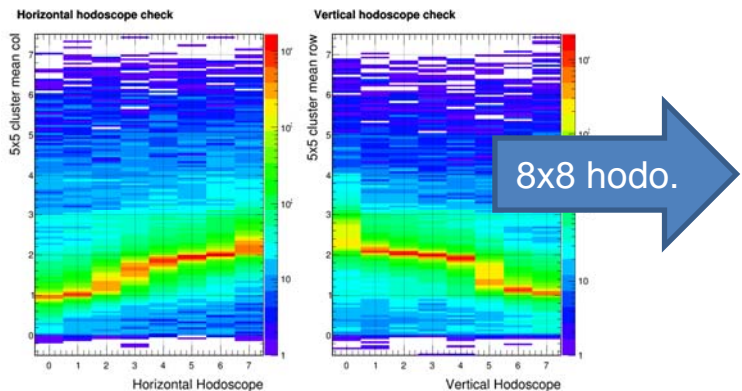
HCAL calibration done with cosmic  $\mu$ 's  
 Edep ~ 750 MeV/1 GeV (Inner/Outer)  
 Inner & Outer HCAL done simultaneously  
 (self triggering w/x16 higher gain)



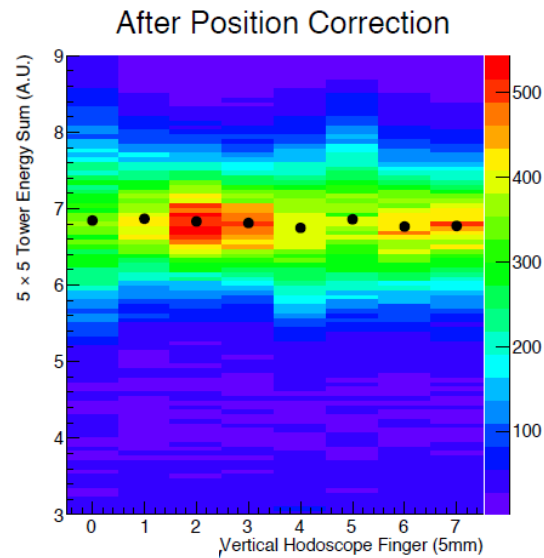
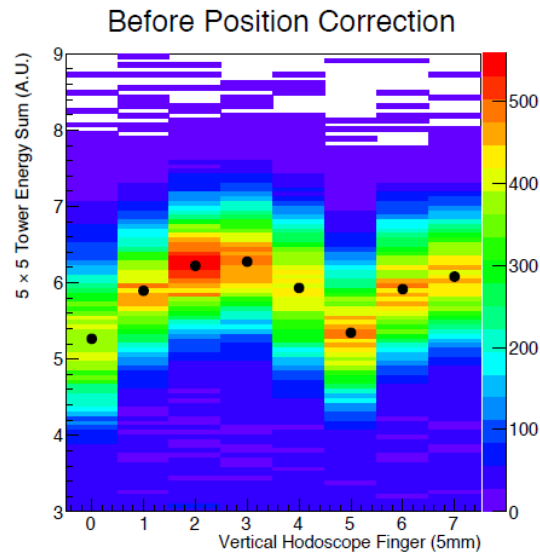
Example of Outer HCAL calibration with cosmic muons

# EMCAL Energy Resolution and Linearity

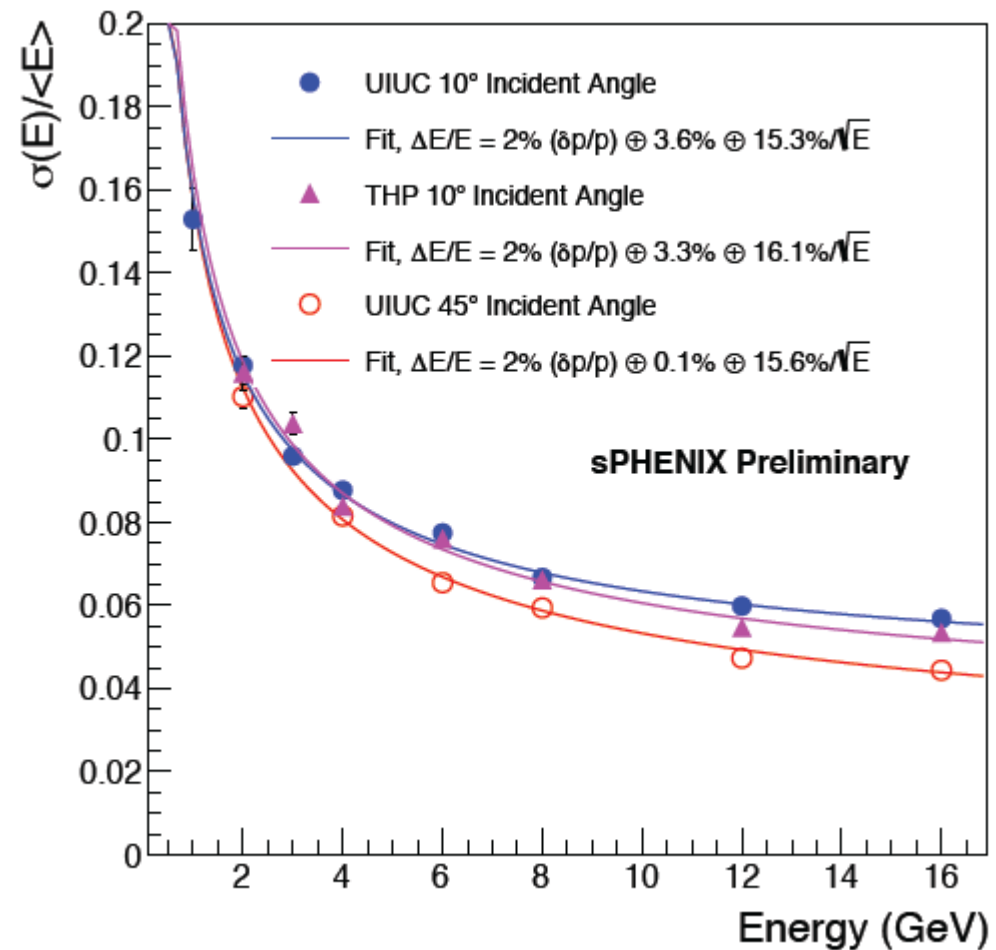
UIUC Block21 high statistics scan



# Correction for Position Dependence



Using Hodoscope (5x5 mm<sup>2</sup> bins)

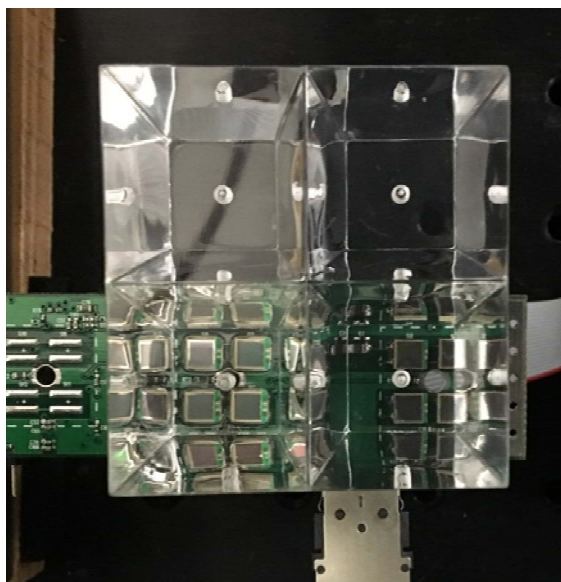
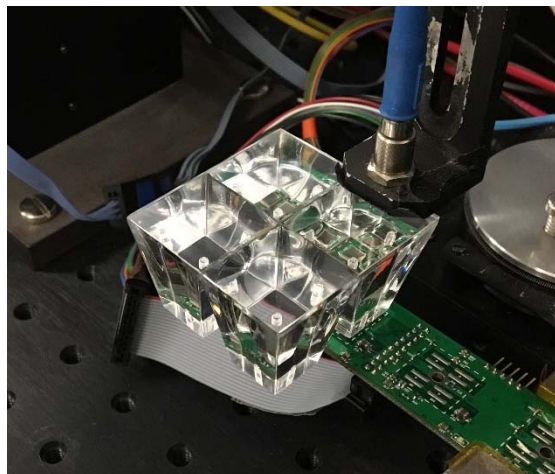


A. Sickles

2016 NSS/MIC, Strasbourg

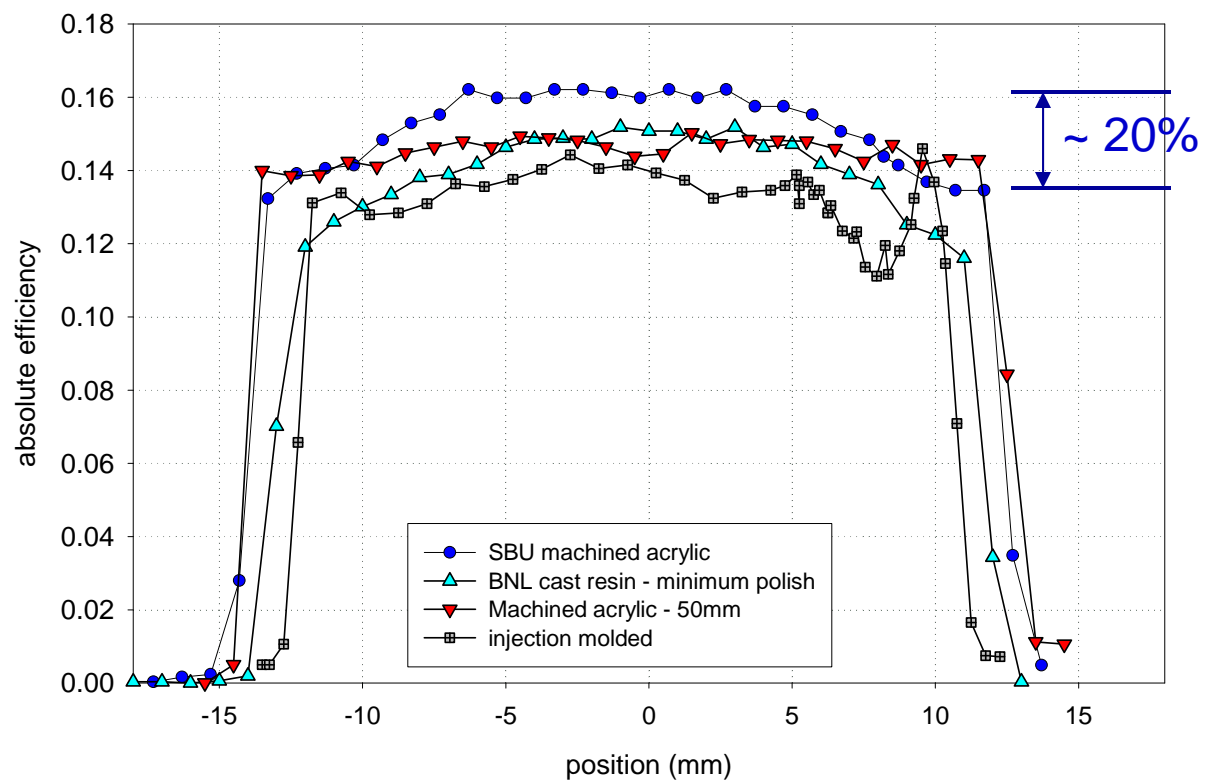


# Light Guide Uniformity



Uniformity scan of various light guides  
Read out with 4 sipms w/rtv coupling

Light guide scanned with 0.47mm fiber (420nm LED light) 1mm above surface.

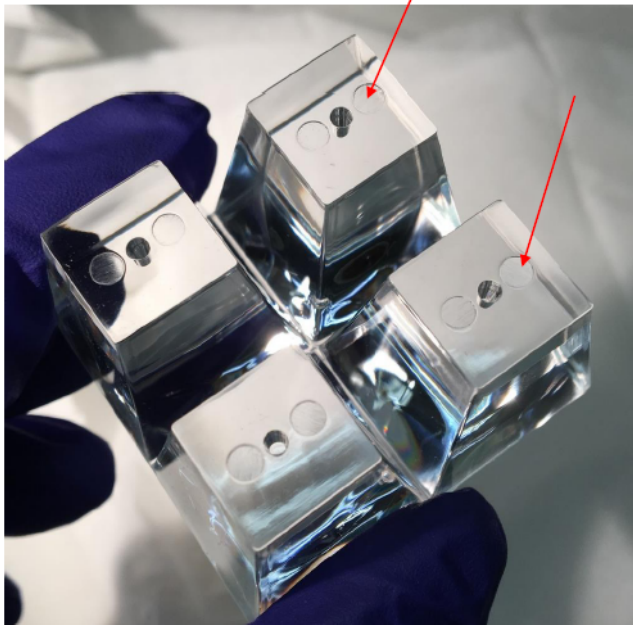


S. Stoll

# Injection Molded Light guides

- ❑ Light guides used in 1D prototype were each machined and polished by hand in the Stony Brook Machine Shop. Cost: \$140 each
- ❑ We clearly can't afford 25K of them at this price so we need to look at other alternatives.
- ❑ Try and make them by injection molding

Markings from mold:



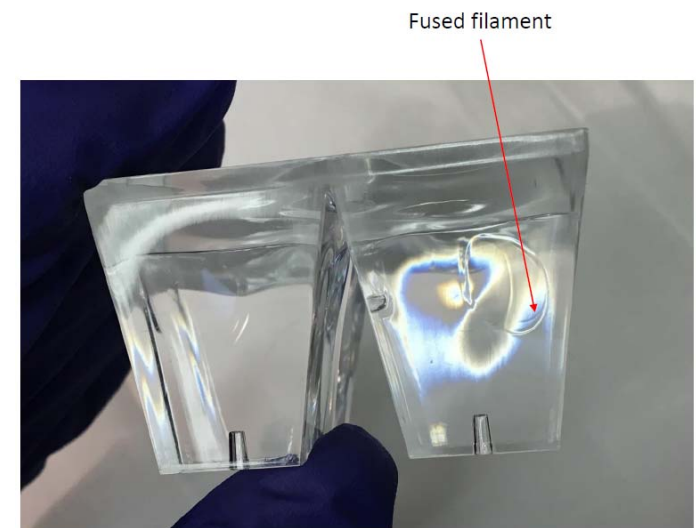
Top: ejection marks

100 pieces produced (~ \$3 ea)

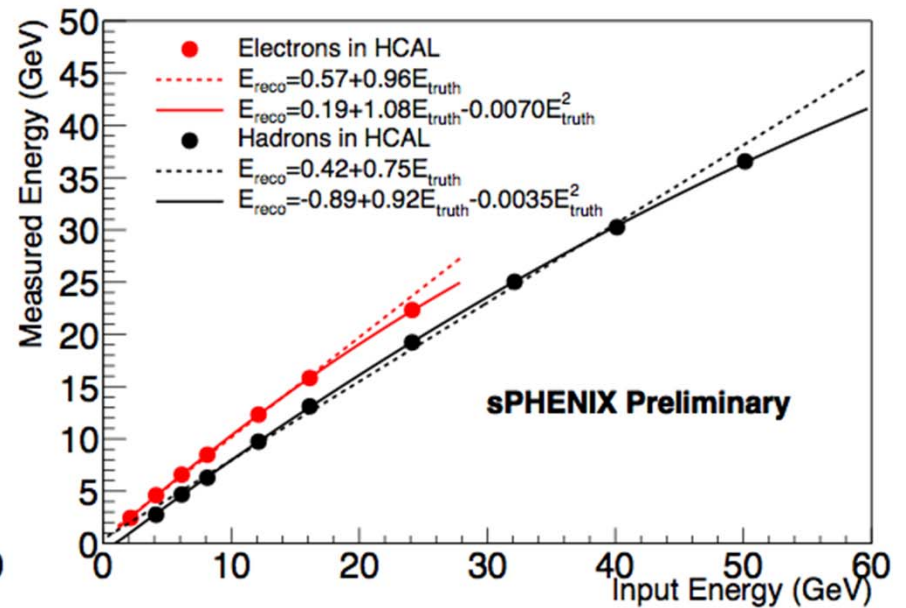
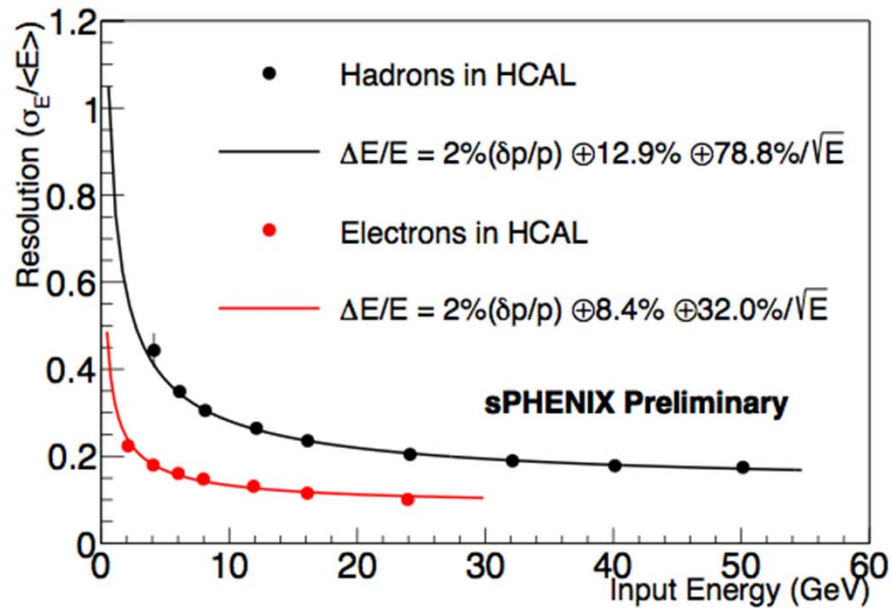
Not bad, but there are many imperfections.

Some can be machined away, others cannot

Overall yield ~ 20%



# HCAL Standalone Resolution

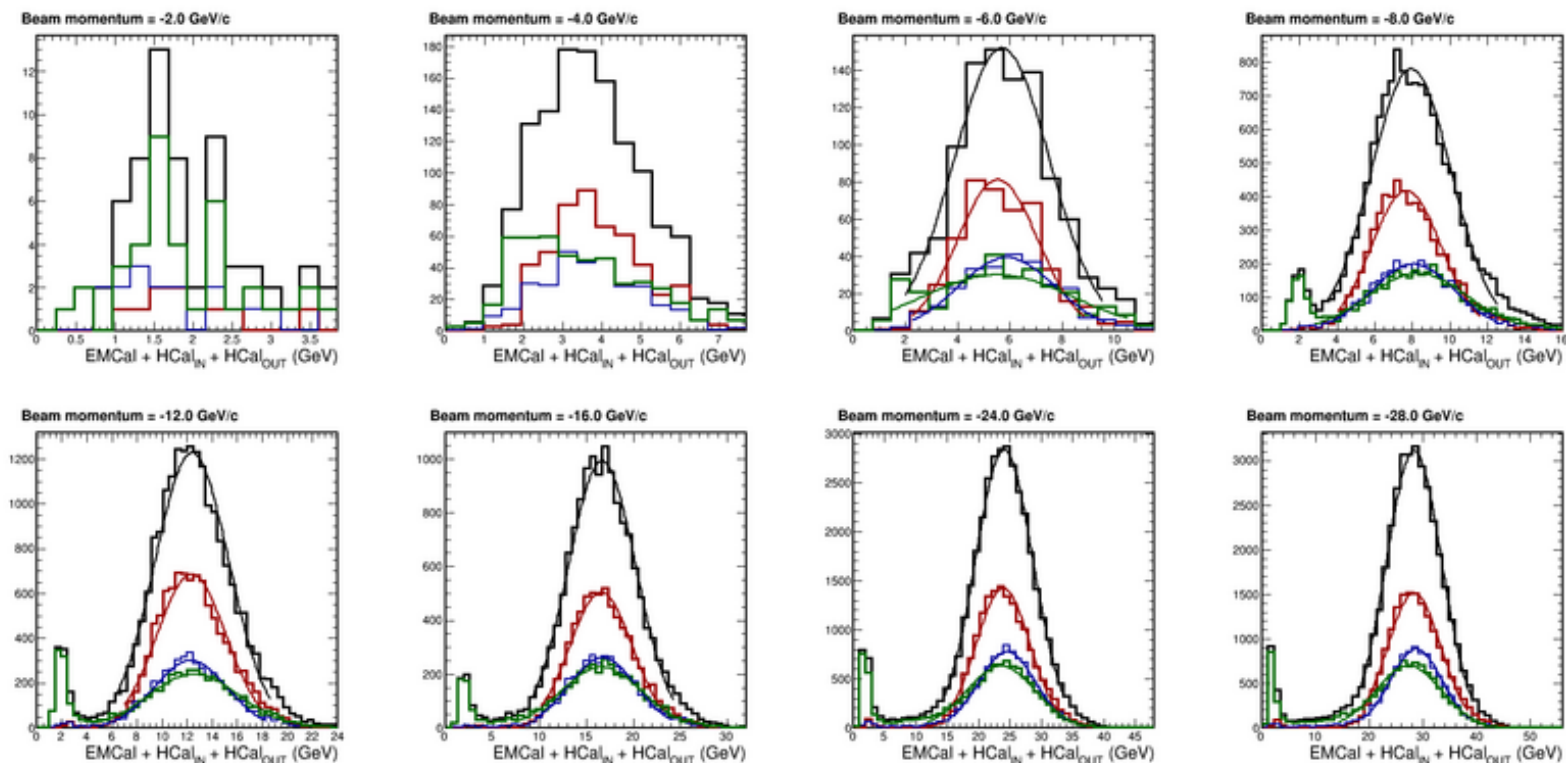




# Combining EMCAL + HCAL Energy

Calibration with hadron showers selected using beam Cherenkovs

(Addition requirements: 4x4 cm<sup>2</sup> hodoscope hit, no veto hit)



Red: Shower starts in EMCAL

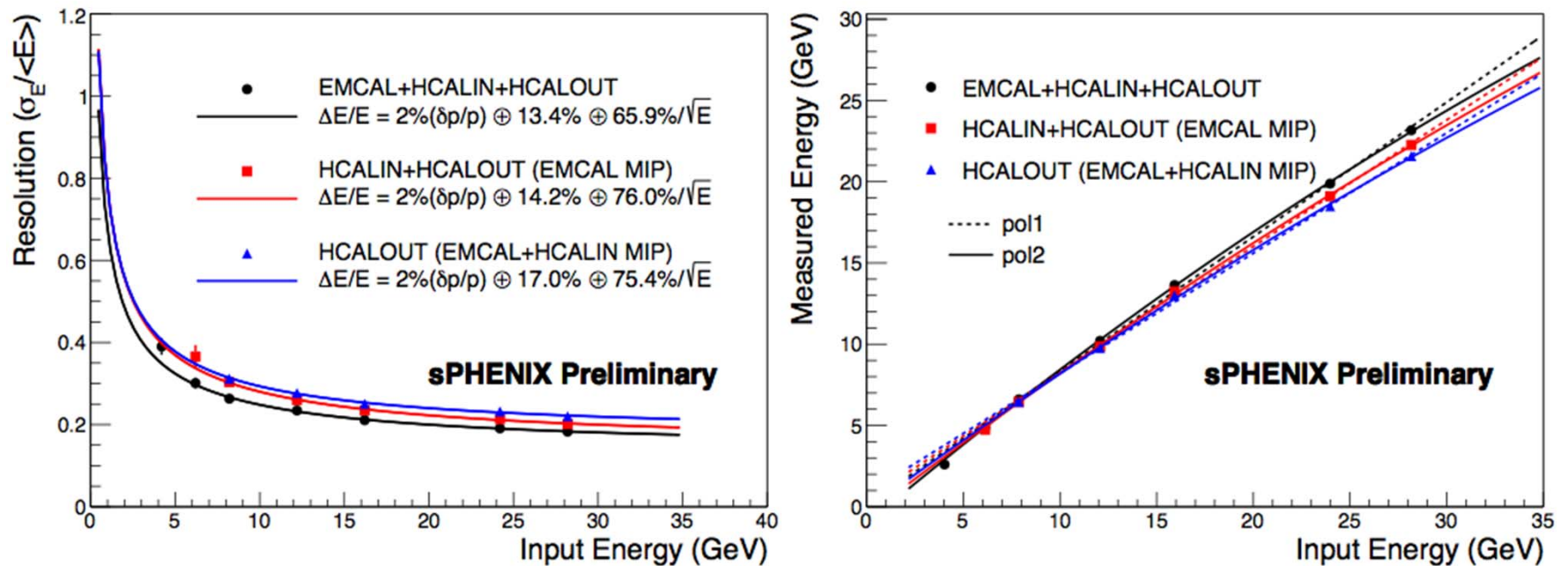
Blue: MIP in EMCAL. Shower starts in Inner HCAL

Green: MIP in EMCAL and Inner HCAL. Shower starts in Outer HCAL

Black: Sum of all showers

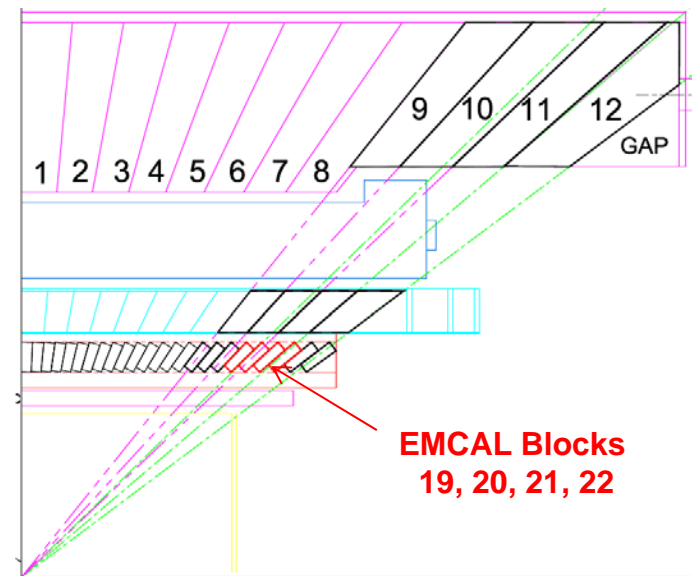
Sets energy scale for adding energies from all three calorimeters

# Combined EMCAL + HCAL Resolution



# 2017 Beam Test

- ❑ New large  $\eta$  prototype will consist of 8x8 2D projective towers made of 16 2x2 tower blocks
- ❑ All blocks are being made at UIUC using their “bath tub” mold technique, which relies heavily on 3D printing
- ❑ Will equip half with injection molded 1” light guides and half with 2” long machined light guides
- ❑ Will be tested along with large  $\eta$  version of the Inner and Outer HCAL reconfigured with new scintillating

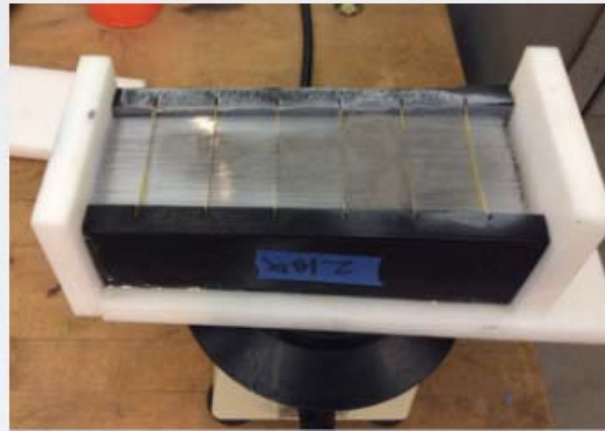




# Module Production at UIUC



**module 21 #1 & 2  
being epoxied**



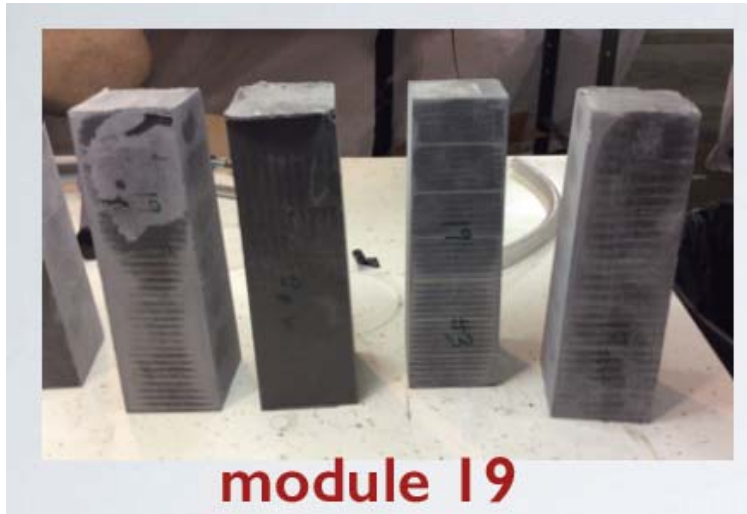
**module 21 #4  
during tungsten fill**



**module 21 #3 & 4 &  
module 22 #3 & 4  
awaiting epoxy**

V. Loggins

# 2D 2x2 Tower Modules Produced at UIUC



V. Loggins